Osseous evidence behind micro-osteoperforation technique in accelerating orthodontic tooth movement: A 3-month study

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Introduction: The study aimed to investigate the effects of micro-osteoperforations (MOPs) on the mandibular bone volume/tissue volume (BV/TV) ratio changes and the rate of orthodontic tooth movement using cone-beam computed tomography images. Another objective was to evaluate the effects of MOP frequency intervals (4 weeks, 8 weeks, and 12 weeks) on the BV/TV ratio and rate of tooth movement. Methods: In 24 participants, 140-200 g of force was applied for mandibular canine retraction. Three MOPs were made according to the scheduled intervals of the 3 different groups: group 1 (MOP 4 weeks), group 2 (MOP 8 weeks), and group 3 (MOP 12 weeks) directly at the mandibular buccal cortical bone of extracted first premolars sites. Cone-beam computed tomography scans were obtained at the 12th week after MOP application. Computed tomography Analyzer software (version 1.11.0.0; Skyscan, Kontich, Belgium) was used to compute the trabecular alveolar BV/TV ratio. Results: A significant difference was observed in the rate of canine movement between control and MOP. Paired t test analysis showed a significant difference ($P = 0.001$) in the mean BV/TV ratio between control and MOP sides in all the frequency intervals groups. However, the difference was significant only in group 1 ($P = 0.014$). A strong negative correlation ($r = –0.86$) was observed between the rate of canine tooth movement and the BV/TV ratio at the MOP side for group 1 and all frequency intervals together ($r = –0.42$). Conclusions: The rate of orthodontic tooth movement can be accelerated by the MOP technique with frequently repeated MOPs throughout the treatment. (Am J Orthod Dentofacial Orthop 2020;158:579-86)

Orthodontic force alters alveolar bone macrostructural and microstructural morphology to facilitate tooth movement. Orthodontic force alters alveolar bone macrostructural and microstructural morphology to facilitate tooth movement. Various surgical techniques have been reported in recent years to reduce orthodontic treatment duration by altering alveolar bone morphology.

In recent years, micro-osteoperforations (MOPs) technique has been used to reduce the duration of orthodontic treatment and to limit the invasive nature of surgical orthodontic procedures. This technique was proved to be effective because it did not involve flap elevation and bone augmentation compared with the previously reported more invasive surgical techniques. Recently, Tsai et al conducted a study on animal models to investigate the rate of orthodontic tooth movement and alveolar bone changes due to MOPs. However, some studies reported no significant increase in the rate of orthodontic tooth movement due to MOP in human experimental model.

Previous studies reported on the osseous response to surgically assisted accelerated orthodontics have mainly focused on the radiographic assessment of bone density changes instead of bone microstructural parameters. Combined assessment of bone mineral density and trabecular microstructural parameters may give more detailed information on bone quality. Various 3-dimensional radiographic modalities are available for evaluating trabecular bone microstructure parameters.
However, this technique is limited for human subjects to the disproportionate exposure of radiations (multidetector computed tomography, high-resolution peripheral quantitative computed tomography), limited range of scanning sites (microcomputed tomography [micro-CT]) and restricted accessibility (high-resolution magnetic resonance imaging).23–26

The effects of MOPs on the rate of orthodontic tooth movement and trabecular bone parameters have been reported on animal models using micro-CT,17,18,26 and it is considered to be the gold standard for assessing radiographic trabecular alveolar bone microstructural parameters. However, its application on the human experimental model is not possible owing to the limited range of scanning sites. Cone-beam computed tomography (CBCT) in dental practice has various advantages over other computed tomography (CT) modalities like rapid scan time, higher spatial resolution, beam limitations, different field of view, isotropic voxels, and dose reduction. Recent human studies have reported the role of CBCT in evaluating bone microstructural parameters.27–30 Research in this aspect is limited despite recent studies showing good results for the bone microstructural assessment using CBCT.27

To limit the radiation exposure per study subject, we investigated the rate of orthodontic tooth movement and bone volume/tissue volume (BV/TV) ratio in the mandible where tooth movement is slower in the mandible and where bone density in the mandible is greater than in the maxilla.31,32

The status of trabecular bone microstructure and the frequency of MOPs are among the factors that may optimally induce the orthodontic tooth movement.19,26 However, these 2 contributing factors have not been reported in any human experimental studies.

This study aimed to investigate the effects of MOPs on mandibular BV/TV ratio changes, and the rate of orthodontic tooth movement, using CBCT images. The other objective was to evaluate the effects of MOP frequency intervals (4 weeks, 8 weeks, and 12 weeks) on the BV/TV ratio and rate of tooth movement.

MATERIAL AND METHODS

This study was a single-center, single-blind, prospective randomized split-mouth clinical trial. The ethical approval was obtained from the institutional Medical Ethics Committee (DF CD1608/0059P), allowing for only 1 limited area CBCT (Kodak 9000; Carestream Health, Rochester, NY) at MOP and control (contralateral) sites for each patient, to assess the mandibular BV/TV ratio at 12 weeks. It must be noted that the CBCT scan was performed just before the placement of MOP in group 1 (4-week interval) and group 3 (12-week interval) at the 12th week of scheduled MOP appointment. Written informed consent was obtained from all participants before the study. CBCT (Kodak 9000) images were used to assess the BV/TV ratio at MOP sides. The rate of orthodontic tooth movement was assessed by comparing the available space between control and MOP sites in 3 different interval groups. Twenty-four participants were selected according to the study selection criteria. Inclusion criteria were (1) age ≥18 years at the start of the treatment, (2) Class I, less than one half unit Class II, or Class III molar relationship, (3) extraction of all 4 first premolar teeth as part of orthodontic treatment, (4) maximum anchorage required using mini-implant, (5) no systemic disease, (6) good oral hygiene and (7) no periodontal disease. Exclusion criteria were (1) significant vertical skeletal discrepancies, (2) systemic diseases requiring long-term antibiotic use, phenytoin, cyclosporin, anti-inflammatory drugs, bisphosphonates, systemic corticosteroids, or calcium channel blockers, (3) poor oral hygiene for more than 2 visits, (4) active periodontal disease, (5) smoking, and (6) medication related to bone remodeling (glucocorticoids, aromatase inhibitors, proton pump inhibitors, immune suppressant, selective serotonin inhibitors, and antiepileptic drugs).

G*Power software (version 3.1.9.2; Universität Düsseldorf, Düsseldorf, Germany) was used to calculate the total sample size of 24 using t tests to achieve a power of 80% and a level of significance of 5% (2 sided), for detecting an effect size of 0.60 between pairs. The effect size was determined on the basis of the mean values of the BV/TV ratio previously reported in MOP studies using micro-CT.17,26 The average calculated effect size was 0.70. However, considering the efficacy of CBCT in measuring the BV/TV ratio compared with micro-CT, we used a lower effect size (0.60). However, 30 samples were selected to compensate for any dropouts during the study.

The mandibular dentition was bonded with preadjusted edgewise brackets (3M Unitek, Monrovia, Calif; 0.022 × 0.028-in slot in MBT prescription), and the first and second molars banded (3M Unitek; 0.022 × 0.028-in slot in MBT prescription). Mini-implants were inserted in the keratinized gingiva between the second premolars and first molars bilaterally for both indirect and direct anchorage purposes. The canine retraction was done 1 month after insertion of a stainless-steel working archwire (0.018 × 0.025-in) (Stainless Steel Accuform; Dentsply GAC, Bohemia, NY), using power chain (Alastik elastomeric chain; 3M Unitek), with 140–200 g of force (measured directly using a Correx Force Tension gauge; Haag-Streit Diagnostics, Koniz, Switzerland), engaged
from the canines to the mini-implants. The distance of canine movement was recorded every 4 weeks with digital calipers accurate to 0.01 mm, for 12 weeks.

MOPs were performed according to the scheduled intervals of the 3 different groups (Fig 1). At the experimental site, 3 MOPs were made directly at the buccal cortical bone of extracted first premolars sites, at equidistance from the canine and second premolar under local anesthesia. The MOPs were 2 mm apart in vertical direction and 3 mm in depth. The first MOP was placed starting at the horizontal level of the cervical margin of the canine tooth and extending apically. The Orlus Extra Thread Mini-Implant (Ortholution, Seoul, Korea), 1.6 mm in width and 6 mm in length with a rubber stopper at a measured length (depth of MOP at 3 mm and soft tissue thickness was taken into consideration) was used to perform MOPs. Group 1 received 4 sessions of MOPs at week 0 (baseline), 4, 8, and 12. Group 2 received 2 MOPs at week 0 (baseline) and 8. Group 3 received 2 MOPs at week 0 (baseline) and 12. In the 12th week after the MOP application, CBCT scans of the mandibular left and right quadrants (both control and intervention side) were acquired.

CBCT (Kodak 9000) exposure parameters were set at 8 mA, 70 kV, exposure time of 10.8 seconds, and a voxel size of 76 µm, axial slice thickness of 76 µm, 4 x 4 cm FOV and 360° arm rotation. CBCT images were converted into Digital Imaging and Communications in Medicine file format and exported to ImageJ software (version 1.50i). It was used to convert Digital Imaging and Communications in Medicine files into a series of bitmap image files. The images were then exported to CT Analyzer software (version 1.11.0.0; SkyScan, Kontich, Belgium) for the trabecular BV/TV ratio analysis.

Two observers (orthodontic postgraduate students) were blinded to the frequency of MOP while analyzing the BV/TV ratio using CT Analyzer software as CBCT files were labeled by random numbers.

A region of interest (ROI) of 14.8 mm was vertically selected between canine and second premolar teeth in CT Analyzer software. A polygonal ROI was used to mark the region of interest (Fig 2). A dynamic interpolation was applied to create a uniform selection of the ROI adaptively. The selected ROI was then binarized using a threshold value that was set to allow complete visualization of the mandibular buccal cortical plate (Fig 3). The binarized image was analyzed to get the percentage of the BV/TV ratio.

**Statistical analysis**

Intraclass correlation coefficient analysis was performed on 5 randomly selected samples to investigate the interexaminer reliability between 2 examiners (N.H.K.T. and M.K.A.) analyzing the BV/TV ratio using CT Analyzer software. Paired t test analysis was used twice to compare the amount of canine retraction and the BV/TV ratio between all MOP and control sides, and subsequently for each specific MOP interval. Pearson correlation analysis was employed to investigate the correlation between the BV/TV ratio at the MOP side and the rate of canine tooth movement for each frequency interval. All the data analysis was performed using SPSS software (version 20; SPSS, Chicago, Ill).

**RESULTS**

Twenty-four participants were stratified into 3 study groups (4, 8, and 12 weeks) on the basis of frequency intervention intervals (Fig 4). Ethnically, there were 11 Malay samples (45.8%), 10 Chinese samples (41.7%), and 3 Indian samples (12.5%). Sex and ethnic distribution were not equal within the study groups owing to the limited sample size; as a result, sex variance was not assessed in the present study (Table I).

The value of intraclass correlation coefficient analysis was 0.893 for interexaminer reliability, indicating a strong agreement in the reproducibility of measurements between the 2 observers. Paired t test analysis showed that the difference in the mean values for the amount of canine retraction was statistically significant between control and MOP sides and was also statistically significant for all the frequency intervals (Table II) (Supplementary Table).

Paired t test analysis showed a significant difference between control and MOP sides in the BV/TV ratio for all the intervention groups analyzed together (\( P = 0.001 \)). However, on the basis of each frequency interval, the results indicated that only group 1 (frequency interval, 4 weeks) showed a statistically significant difference in
the BV/TV ratio ($P = 0.014$) (Table III) (Supplementary Table).

A strong negative correlation was observed between canine retraction and the BV/TV ratio at the intervention side for group 1 (frequency interval, 4 weeks) and all frequency intervals together. No significant correlation was found for groups 2 and 3 (frequency interval, 8 and 12 weeks, respectively) (Table IV).

**DISCUSSION**

The present study could not assess sex and ethnic variance for the effects of MOPs on the changes in the

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**Fig 2.** Selection of the ROI between canine and second premolar teeth using a polygonal marking in CT Analyzer software.

**Fig 3.** The range of threshold values used to binarize the image in CT Analyzer software.
mandibular BV/TV ratio, in relation to the MOP effects on the rate of orthodontic tooth movement.

The reason for this limitation of the study was that we get more female patients than male patients.

Micro-CT has been used as a radiographic tool to assess alveolar bone microstructures in experimental animal studies. However, its application in human models is limited owing to constrained scanning range and high

Table I. Sample size distribution based on sex and frequency intervals of MOPs

<table>
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<th>Study group</th>
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The reliability of CBCT in assessing trabecular alveolar bone microstructural parameters such as the BV/TV ratio is comparable to that of micro-CT. Therefore, in the current study, CBCT was used to assess the effect of MOPs on the BV/TV ratio and rate of tooth movement. The current finding is in parallel with a micro-CT study that reported a lower value for the BV/TV ratio in the MOP group compared with the non-MOP group. In concordance with the results of another micro-CT study, a significant reduction in the BV/TV ratio was also observed when the number of MOPs increased.

Various 3-dimensional radiographic modalities are available to assess trabecular alveolar bone microstructural parameters. However, there are no universally accepted radiographic protocols in assessing trabecular alveolar bone microstructural parameters. Micro-CT is considered to be the gold standard for alveolar bone microstructure assessment. However, it can only be used for animal experiments and small specimen studies. Recent in vitro studies have shown a good correlation of trabecular alveolar bone microstructure assessment between micro-CT and CBCT. Therefore, the present study used CBCT to clinically compare the trabecular BV/TV ratio between control and MOP sides.

The effect of frequency intervals of MOPs on the trabecular BV/TV ratio is very rare in the literature. Investigation on the mean values of the BV/TV ratio for different MOP intervals demonstrated a significant difference ($P = 0.014$) between control and MOP sides at the 4-week frequency interval (group 1) (Table III). Because the bone healing time is generally between 6 and 8 weeks, we hypothesized that the effects of MOPs on the BV/TV ratio could not be detected in the longer interval groups (8 weeks and 12 weeks). The reduction in the BV/TV ratio due to MOPs could be 1 of the factors in accelerating orthodontic tooth movement. Therefore, the influence of the BV/TV ratio on tooth movement can only be observed in group 1. For canine movement, the mean values were significantly different between control and intervention sides for...
all 3 interval groups (group 1, $P = 0.001$; group 2, $P = 0.006$; and group 3, $P = 0.004$). However, group 1, which received MOP at shorter intervals (4 weeks), showed the greatest canine movement compared with the other groups. Further studies should be conducted with an interval time shorter than 6 weeks to observe the effect of MOP on tooth rate movement precisely.

The current results showed a strong negative correlation between the rate of canine movement and bone volume fraction at the MOP in the 4-week interval group. This finding indicates that the rate of canine tooth movement will increase when the BV/TV ratio decreased (Table IV). However, this pattern was not evident in the other interval groups (weeks 8 and 12). This result could be due to the lesser MOP frequency received in the latter groups compared with group 1, which resulted in an increased BV/TV rate and reduced canine tooth movement.

This study demonstrated a significant effect of MOP on the BV/TV ratio. However, the current result might be affected by the low contrast-to-noise ratio owing to the small CBCT voxel size used (76 μm) during the scanning.34 With the advancement in CBCT technology and improvement in voxel resolution, the osseous changes can be more precisely detected in future orthodontic tooth movement studies. The results of this study indicated that the 4- and 8-week interval groups did not show a significant correlation between the rate of canine movement and bone volume fraction. This finding could be due to the fact that the sample size was not large enough within each intervention group to detect variation in the BV/TV ratio using CBCT. This result is a reflection of the sample size limitation of our study. Future studies should be conducted using a larger sample size to validate the effects of MOPs on the changes in the mandibular BV/TV, in relation to the MOP effects on the rate of orthodontic tooth movement.

CONCLUSIONS

The rate of orthodontic tooth movement can be accelerated by the MOP technique with frequently repeated MOPs throughout the treatment.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2019.09.022.

REFERENCES


### Supplementary Table. Raw data of canine tooth movement and BV/TV ratio in control and MOP groups

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